# Valuation of soil health ecosystem services

Vermont Payment for Ecosystem Services Technical Research Report #5

Version 1

Prepared for the Vermont Soil Health and Payment for Ecosystem Services Working Group

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# Valuation of Ecosystem Services from Improved Soil Health in Vermont

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## Executive Summary:

- Soil health, and the practices meant to support it, can contribute to human well-being far beyond direct impacts on agricultural productivity.
- Ambitious improvements in soil health on Vermont farms could yield $34/acre/year in several ecosystem services combined, providing a total value of nearly $17 million/year across all Vermont agricultural land.
- Increased carbon storage could produce $14/acre/year in climate mitigation benefits.
- Reductions in phosphorus losses could yield $15/acre/year in water quality benefits.
- Reductions in erosion could yield $3/acre/year in reduced damages to waterways.
- Increased water retention could yield an average of >$1/acre/year in reduced damages to downstream communities, with values over $10/acre in some locations.
- These estimates are preliminary, and subject to many uncertainties, but demonstrate substantial benefits which could justify serious policy efforts to support, measure and pay for soil health improvements on Vermont farms.
- This report focuses on in-field improvements in soil health, and thus does not include edge-of-field and whole-farm practices. The impacts of these other practices on ecosystem services are often better studied than those of soil health. We refer to this research below, but estimating their economic values is beyond the scope of this report.


## Introduction:

For millennia, farmers have recognized the importance of soil health for crop productivity and resilience. Recently, scientists, policy-makers and farmers have become interested in the non-agricultural benefits of healthy farmland soils. Healthy soils can support climate mitigation through carbon sequestration, protect the health of waterways by retaining nutrients and sediments, protect downstream communities by absorbing water and protect the air by regulating gaseous emissions. These and other ecosystem services provided by healthy soils may meaningfully contribute to the health and vitality of communities and ecosystems.

In recent years, farms have struggled financially and awareness of environmental problems have grown. Across the world, policy-makers have sought ways to compensate family farms for their environmental stewardship as a means to tackle both these problems. Farmers have organized under the banner of "regenerative agriculture" to experiment with new practices and promote values provided by healthy soils far beyond the farm

Vermont may be well-positioned to become a leader in this movement; family farming and environmental stewardship are central to our collective identity and economy. There have been several efforts to develop a policy framework for soil stewardship, but none have succeeded. In 2019, Act 83 of the Vermont Legislature created a working group to explore payments for ecosystem services as a framework for linking farm supports and environmental stewardship. This report was commissioned as part of this effort.

To design a program to promote soil ecosystem services, it is necessary to generate an estimate of the magnitude of each of the benefits. If we understand the scale and value of benefits, we can then judge the cost-effectiveness of such a program compared with alternatives, such as investments in other natural systems like forests and wetlands, or investments in hard infrastructure. Because improvements in natural systems can affect many different things we care about, putting total benefits in dollar terms helps us to combine different types of benefits and to assess which benefits are largest.

In this report, we present estimates for ecosystem services from soil health using two approaches for four different services. One approach generates estimates based on soil-health practices, and the other approach is based on improvements in soil-health indicators. For soil-health practices, such as converting annual crops to hay, we utilize a set of off-the shelf empirical models widely used to estimate ecological functions on farm landscapes. For soil-health indicators, we make estimates by linking these tools with soil data and statistical models describing how soil-health parameters influence the interaction of soils with water and their environment. We provide rough monetary estimates of the value of these services, using several different standard ecological economics methods. These results are necessarily rough but can help to elucidate the relative magnitudes of different types of benefits.

## Scope:

This report estimates the impacts of soil health practices and soil health improvements on several regulating ecosystem services for the state of Vermont and provides rough estimates of the monetary values of these improvements. The ecosystem services estimated in this paper are: climate mitigation, nutrient retention, erosion control, and flood mitigation. We also briefly address impacts of soil health on nitrogen cycling and pollution, but complexity and uncertainty prevents us from estimating values. While soil health has numerous benefits to yield, crop quality and climatic resilience for the individual farmers and landowners, these benefits are outside of the scope of this report. Instead, we focus on public goods provided to society at large, to inform a potential PES scheme for soil health in Vermont.

In keeping with the mandate of this project to focus on soil-health, we excluded numerous management and land use changes that could have large impacts on the same ecosystem services. These include wetland restoration/construction, forested riparian buffers, conversion of agricultural land to forest, artificial ponds and stream de-channelization. While these “edge-of-field” or “whole-farm” strategies may have large impacts on the ecosystem services of interest, they are not directly “soil-health” related. The impact of these interventions on ecosystem services is also better-studied than the impact of soil health. A full assessment of the potential of farms to provide ecosystem services should consider impacts of all potential management options.

## Overall methods:

This report estimates ecosystem services and their values using two distinct perspectives (Figures 3,4). First, we estimate the increase in ecosystem services from ***soil health practices***, using the scenarios developed for Task 2 of our technical services contract to the PES Working Group as examples. See Table 1 for more details of these practices. For this, we use an array of existing empirical models, including the Universal Soil Loss Equation, the Curve Number Method and the Vermont Phosphorus Index to estimate the change in ecosystem services. All these scenarios take row crops with conventional tillage as their baseline for comparison.

**Table 1: Descriptions of Soil Health Practice Scenarios used in this Report. Row crops with conventional tillage was used as the baseline for comparison**

| Soil Health Practice Scenario | Description |
|---|---|
| Corn BMPs | No-till / zone-tillage, winter rye cover crop & manure injection. These represent strongly-promoted BMPs by the state of VT for water quality. |
| Corn-Hay Rotation | Replacing Continuous Corn with a rotation that is half-corn, half-hay without implementing the BMPS mentioned above |
| Permanent Hay | Long-term perennial hay crops. |
| Pasture | Long-term perennial pasture[1]. |
| Vegetable BMPs | Annual vegetable production with greatly reduced tillage with both winter and summer cover crops. This scenario uses vegetables grown conventional-tillage and no cover-crop as its baseline. |

[1] We do not attempt to model or define different pasture management styles, which may have very different impacts. If careful pasture management has large impacts on ecosystem services, it will be due to improve soil health, and the benefits would best be reflected through estimating the direct impacts of soil-health.

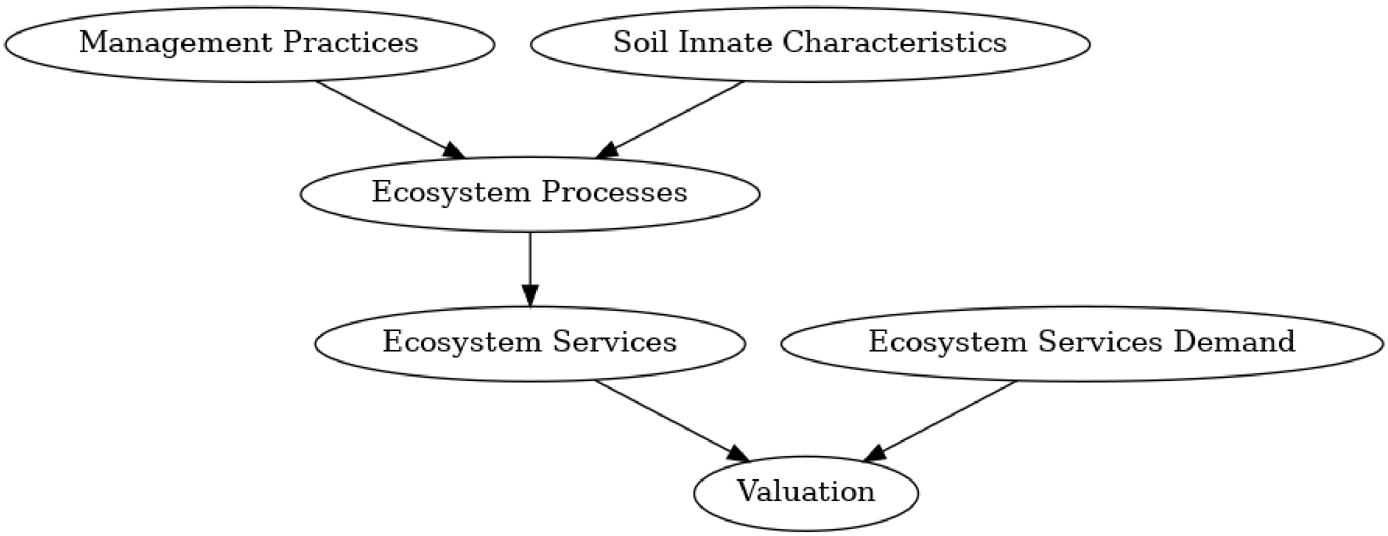


**Figure 3: Conceptual Model for Estimating Impacts of Soil Health *Practices* on Ecosystem Services.**

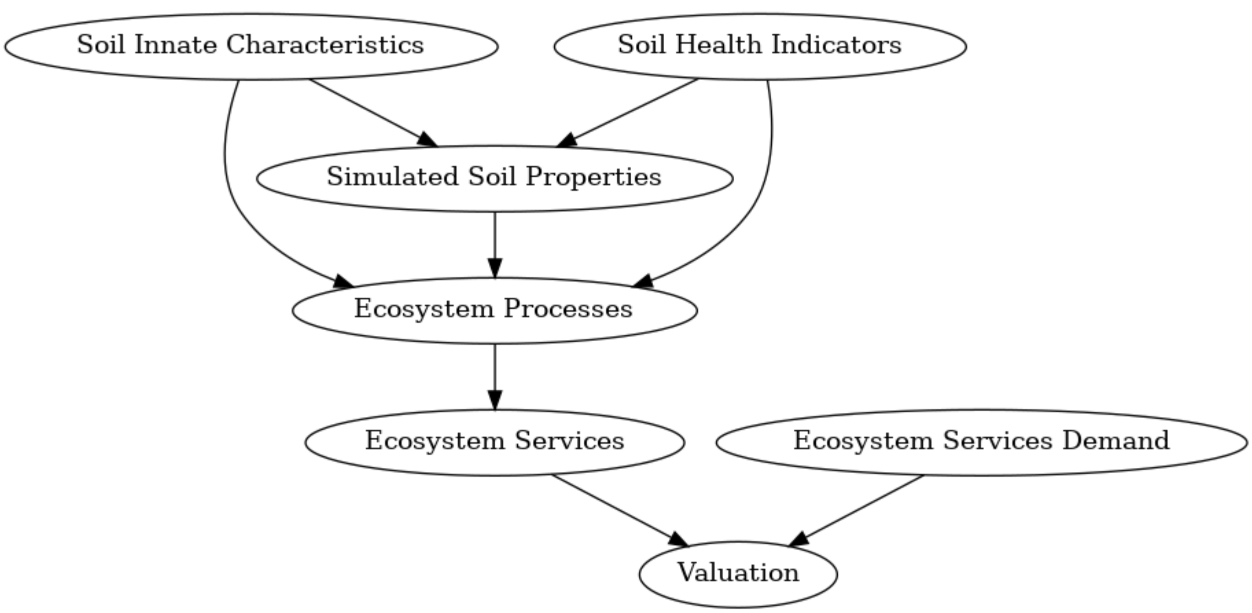


**Figure 4: Conceptual Model for Ecosystem Services Assessment of Soil Health *Indicators***

Second, we estimate impacts of changes in **soil-health *indicators*** on ecosystem services. We use data from the NRCS Soil Characterization Database (Reinsch & West, 2010) to define innate characteristics and reference conditions for Vermont soil series. Innate characteristics are those that don't change with management, such as soil particle-size distribution. Reference conditions are used as typical baselines for conditions that are potentially impacted by management, such as Soil Organic Matter, Bulk Density and depth of each soil horizon. Soil innate characteristics and soil health indicators are used to simulate other soil properties, such as soil erodibility, plant available water capacity and saturated hydraulic conductivity. These parameters are then used to simulate changes to the ecosystem services of interest, using similar tools to those used for soil indicators.

We present two scenarios for moderate and large changes in soil-health, and estimate their impacts on various ecosystem services, as compared to the reference state of the soil.

These soil health scenarios are:

**"Best":** Soil Organic Matter in the A horizon is 50% higher than the reference condition and bulk density 20% lower.

**"Good"** : Soil Organic Matter in the A horizon is 25% higher than the reference condition and bulk density 20% lower.

For each scenario, we simulate these changes on 10 different common agricultural soil-series: Tunbridge, Winooski, Agawam, Windsor, Covington, Vergennes, Cabot, Hadley, Hamlin and Georgia, and present average results, sometimes grouped by soil characteristics.

We do not attempt to estimate the impact of soil health practices on soil health, and then the impacts of soil health on ecosystem services. We hesitate to do this because most tools used to assess the impact of practices on soil ecosystem functions and services do not allow us to partition between their *direct* impact on soil ecosystem services and their impact which is mediated through soil health. For instance, the NRCS Curve Number method estimates lower runoff from land that is in permanent grassland than land that is growing corn. This is due to improved soil health, greater vegetative cover and other differences, but the method gives us no way to disentangle the portion of the impact that is due to soil health itself.

## Simulating Impacts of Soil Properties:

Bulk Density and Soil Organic Matter are important indicators of soil health, but their impacts on many important ecosystem processes, and therefore ecosystem services are mediated through their impacts on *other soil characteristics*. Many of these other soil properties can, in principle, be measured, but would not be feasible to include in a PES program. Instead, these characteristics, including plant available water capacity, porosity, saturated hydraulic conductivity and soil erodibility are simulated through a series of pedo-transfer functions[2]. These equations are used to estimate unknown soil properties based on known soil properties.

In this report we estimate the impacts of two different improvement scenarios for several different common Vermont Agricultural Soils and present averages of these results. The two improvement scenarios are the "high" scenario: Soil Organic Matter increases by 50% and bulk density declines by 20% and the "medium" scenario: SOM increases by 25% and bulk density declines by 10%. In both scenarios, these improvements are confined to the upper layer (A horizon) of the soil, and the decrease in bulk density is compensated for by increasing the depth of the A horizon to keep the mass of soil in the A horizon constant. For reference, agricultural soils in Vermont have average SOM contents of roughly 4.3% and bulk density of about 1.35, with substantial heterogeneity across soil types. But this average soil would see SOM increase to 5.4% or 6.5% and its bulk density decrease to 1.22 g/cm^3 or 1.08 g/cm^3 in the good and best scenarios, respectively.

[2] A pedo-transfer function is an equation that predicts an unknown soil property based on several known soil properties. For instance, if I know the texture of the soil, (as % sand, % silt and % clay) and the soil organic matter content, what is the expected water content of the soil at saturation?

## Results Summary

Overall, improvements in soil health and adoption of soil health practices have the potential to produce substantial benefits for Vermonters and people around the world. Below we summarize the results of our valuation estimates for each service.

**Carbon Storage Benefits** are substantial, valued at $14.26/acre/year in the "best" scenario, and $7.13/acre/year in the "good" scenario. We calculate these based on the reduction in warming each year due to reduced atmospheric carbon.

**Flood mitigation benefits** have the lowest valuations, but also the most spatially variable. Average values are roughly $1.97/acre/year for the "best" scenario and $0.89/acre/year for the "good" scenario. These values are relatively low largely because farmland in Vermont is commonly situated relatively low in sub-watersheds, and therefore has relatively fewer downstream areas to impact compared to other runoff-generating land cover types. A small minority of farm fields have downstream neighbors at risk, and those fields have potential flood-mitigation values that are 5x or 10x higher.

**Erosion reduction benefits** are also relatively small for most farm fields- $1.30/acre for the "good" scenario and $2.59 for the "best" scenario. These benefits are proportional to the scale of current erosion losses; fields that are flat and already have extensive soil-cover will have much smaller reductions than steeper fields or those currently in row-crops.

**Phosphorus retention Benefits** are the largest in dollar terms, but also the one with the largest uncertainty. Average values for the "good" scenario are $8.29 /acre/year, while average values for the "best" scenario are $15.82. Improved soil health is **not** likely to reduce P loading from soils with pattern tile drainage or other direct sub-surface connections to surface-water. Like erosion, P-mitigation benefits from improvements in soil health are highest where potential for P loss is highest, and in watersheds where P loading is a larger problem.

Beyond the four ecosystem services we were able to value, two more deserve mention:

**Nitrogen Retention Benefits** are difficult to characterize because nitrogen can leave farm fields and damage the environment through many pathways, and practices and soil conditions that reduce one pathway may increase another. We present general estimates of the magnitude of harms from N losses from Vermont farms and demonstrate that these harms are large enough that moderate mitigation would generate substantial benefits.

**Soil Biodiversity Benefits** could be valued in several ways, but producing a monetary valuation was beyond the scope of this report.

Under the "best" scenario of soil health improvement, we estimate that farms could be credited with providing an average of $34/acre/year worth of combined ecosystem services (Figure 1). Under the "good" improvement scenario, farms could be credited for $17/acre/year. Our analysis using soil health practices (Figure 2) estimates all management improvements create a total value over $40/acre/year.

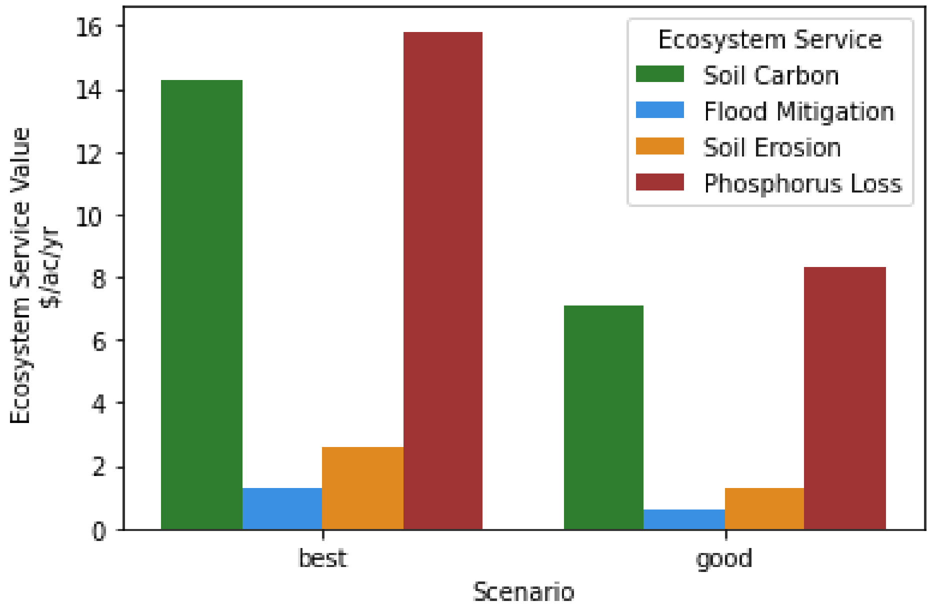


**Figure 1: Valuation of Improved Ecosystem Services for Two Soil-Health Indicators Improvement Scenarios in dollars per acre per year.**

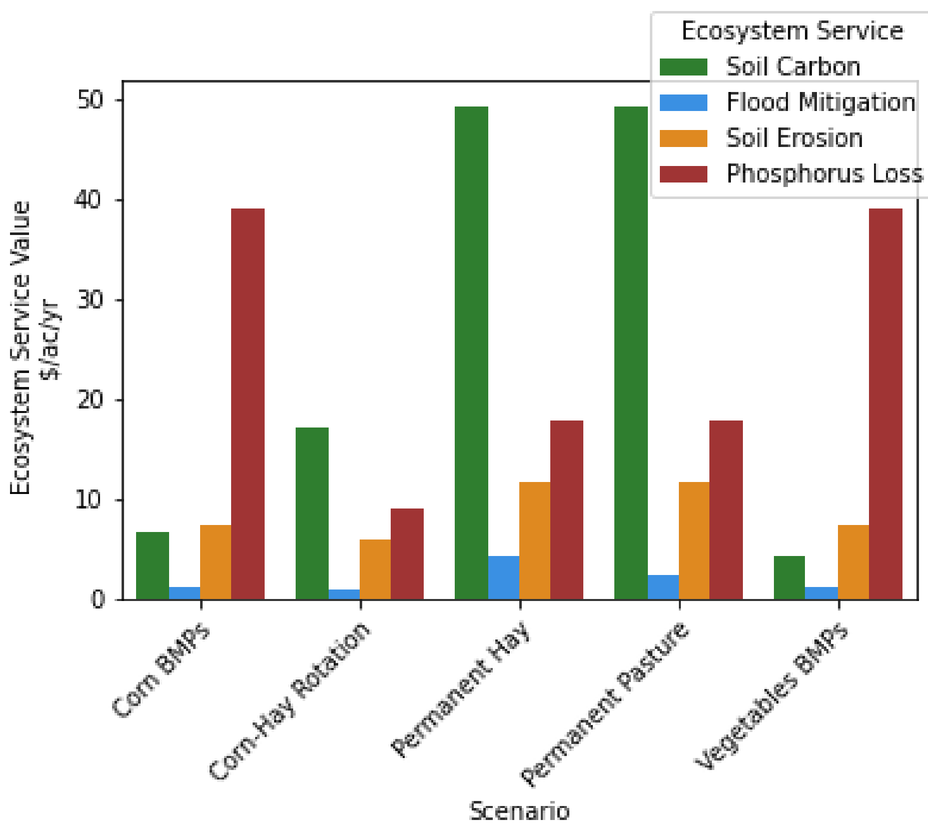


**Figure 2: Valuation of Ecosystem Services from Changes in Soil-Health Practices in dollars per acre per year.**

## Detailed methods and results for each ecosystem service

### CLIMATE REGULATION

Healthy soils can mitigate climate change by storing carbon that would otherwise be in the atmosphere. Additionally, soil health and soil health practices can influence the production of other greenhouse gases from soils, especially methane and nitrous oxide.

Globally, soils hold an enormous amount of carbon; roughly 4 times as much carbon as is currently in the atmosphere. Increasing the carbon content of soils may be an efficient way to mitigate climate change. Voluntary and regulatory markets for carbon storage provide make carbon storage in farmland by far the most commonly marketed ecosystem service from agriculture. Various schemes have enrolled millions of acres worldwide, paying farmers to capture and sequester carbon. Because soil carbon is directly measured as a soil-health indicator, there are fewer elements of uncertainty in the relationship between the soil health metrics and the ecosystem services of interest.

**Valuing Carbon Storage:**

There are two general approaches to valuing carbon sequestration. First, we may multiply the carbon sequestered by the Social Cost of Carbon, as calculated by the EPA, other government agencies or academic researchers. The EPA's social cost of carbon for the year 2021 is $51/ton of CO2 (Interagency Working Group & others, 2021). This would be equivalent to $186/ton of soil organic matter. Alternately, we may compare them to the prices paid by voluntary or compliance-based offsets markets or other corporate programs. The Boston-based Carbon-Offset start-up Indigo Ag (Indigo Ag, 2022) currently guarantees prices in range of $10-$15/ton of CO2, while the company Nori allows farmers to sell offsets for $15/ton (*Nori Carbon Removal Marketplace*, 2022). These prices convert to $53 for each ton of organic carbon added to farm fields.

A major area of concern for carbon sequestration payments is permanence. If a company pays for a carbon offset, or a government pays to reduce damages from carbon, that payment assumes that this carbon is permanently removed from the atmosphere, or at least removed for many decades. If this soil carbon is instead released back into the atmosphere, only a small proportion of these damages would be averted from the short-term storage of carbon, and the value of the carbon storage is greatly reduced.

Most carbon-offset programs deal with this difficulty by enforcing contracts on farmers, obligating them to continue their climate-friendly farming practices. This option seems unlikely for a state-run PES program. Some offset-generating carbon sequestration programs assume that not all carbon will be permanently stored and may reduce payments accordingly. This approach could be taken by a soil PES program. Another approach would be to subtract the value of carbon losses from payments to the farmer generated by other ecosystem services. For purposes of this document, we use a 50% withholding rate, such that farmers are only paid for 50% of the carbon they sequester in the fields.

Carbon storage values can be annualized using the "social cost of radiative forcing" as described by Rautiainen and Lintunen (2017). From their estimates, the social benefit of withholding 1 metric ton of $CO_2$ from the atmosphere for 1 year is $0.44. Adjusting this value down to account for lower prices for offsets, we calculate an ecosystem service valuation of $1.09/Ton of Soil Organic Carbon for each year stored[3].

**Biophysical Methods:**

For Carbon Storage based on practices, we use estimates from the research literature compiled during task 2. For Carbon Storage based on soil health indicators, we simply use the additional carbon in the simulated soil layers.

**Results:**

Figure 5 estimates annualized increases in soil organic carbon, per acre, per year, for the soil health practices scenarios. These results are presented grouped by soil-texture class, which is the number one influence on how much carbon a soil can hold.

Figure 6 shows the estimated total soil carbon storage increase for the soil-health indicator scenarios. Because the soil-health indicator scenarios include carbon as a state variable, we cannot use them to estimate annual rates of accumulation.

**Variation of Service Provision and Values:**

Because climate change is a global problem, the value of carbon storage is the same no matter where it is stored. For the quantity of carbon stored, farm fields with finer textures, such as clays, have more carbon storage capacity than coarse-texture soils such as sandy loams.

**Caveats and Areas for Further Examination:**

While we have not completed more detailed simulations, in general, increased SOM results in moderate reductions in $CH_4$ emissions, while decreases in bulk density can moderately reduce emissions of $N_2O$. In temperate cropping systems, $N_2O$ emissions are often quite substantial, especially with substantial N inputs from fertilizer, legumes or livestock manure. Methane emissions from soils, however, are relatively small, highly variable, and even sometimes negative. We discuss the general magnitude of $N_2O$ emissions in more detail in the section on nitrogen losses.

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[3] Rautiainen and Lintunen estimate the social cost of radiative forcing as $357/nW/m$^2$. A ton of $CO_2$ sequestered reducing radiative forcing by .00122 nW/m$^2$ at year 9. This give $0.44/Ton Carbon/year. Converting from imperial tons SOC to metric tons $CO_2$ multiplies by 3.34, and their estimate of social cost of carbon is 1/3 higher than typical offset rates.

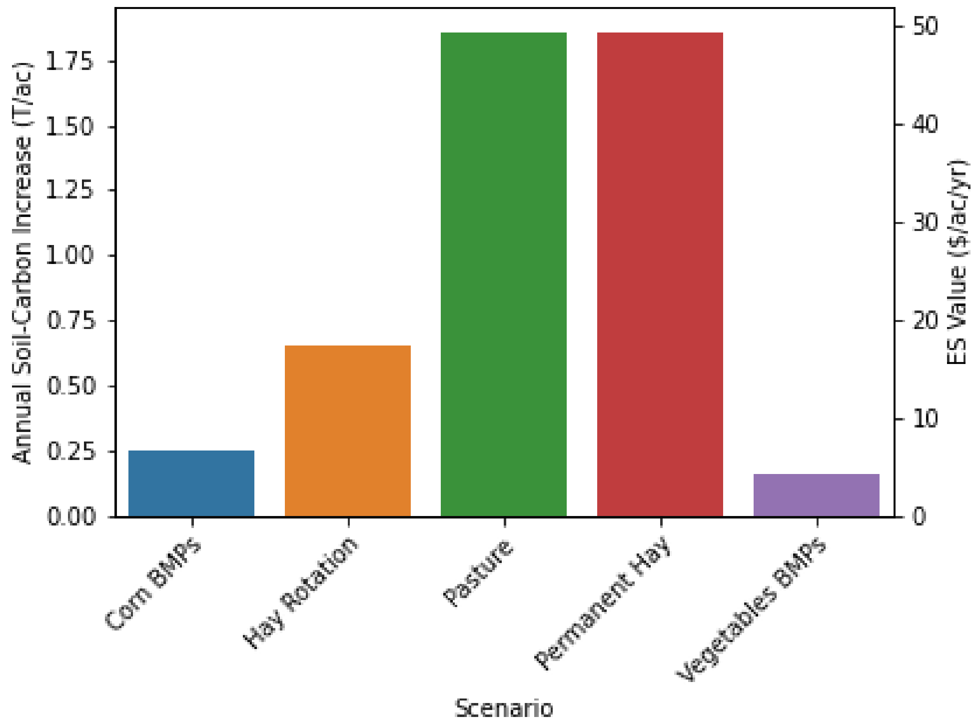


**Figure 5: Total Increase in Soil Carbon by Soil Health Practice Scenario, and Ecosystem Service Value.** ***Note that the Corn to Corn-Hay Rotation Numbers demonstrate the lack of durability in Soil Carbon increases: 5 years in Hay increases Soil Organic Matter dramatically, but almost half of that increase disappears when the field is rotated back into Corn for 5 years.**

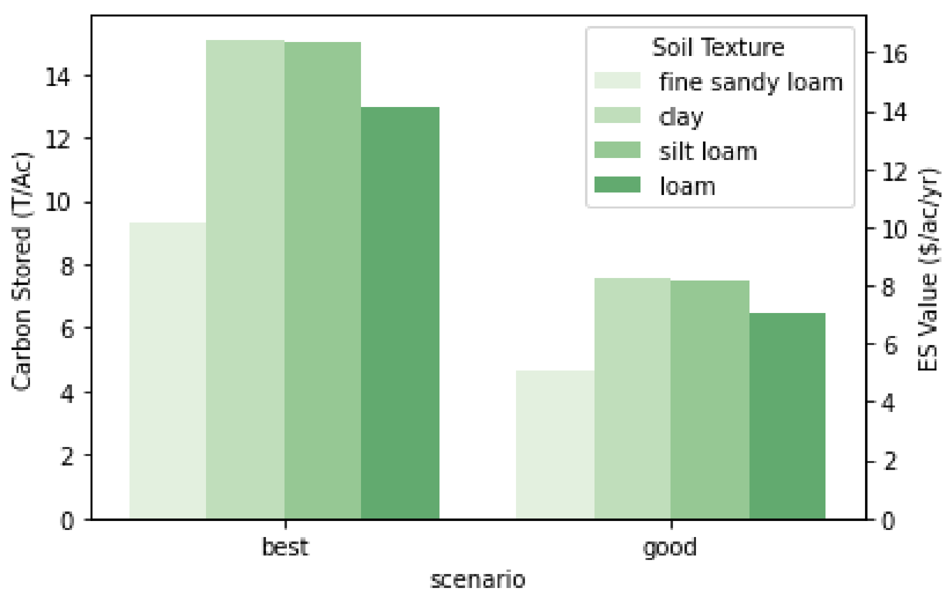


**Figure 6: Total Increase in Soil Carbon by Soil Health Indicator Scenario, and Ecosystem Service Value.**

Despite the one-to-one linkage between Soil Organic Matter as a soil health indicator, and carbon storage as an ecosystem service, there are important complications in measuring soil carbon storage. These relate to the depth of measurement, and its relationship to soil bulk density. Soil organic carbon is usually measured to a reference depth, often 30 cm. If management of a soil results in substantial soil compaction, then more soil material ends up within 30 cm of the surface, increasing measured soil carbon storage, without increasing actual carbon storage (Figure 7). Lee and colleagues (Lee et al., 2009) demonstrate these complications and recommend that changes in bulk density not be used to assess changes in carbon storage.

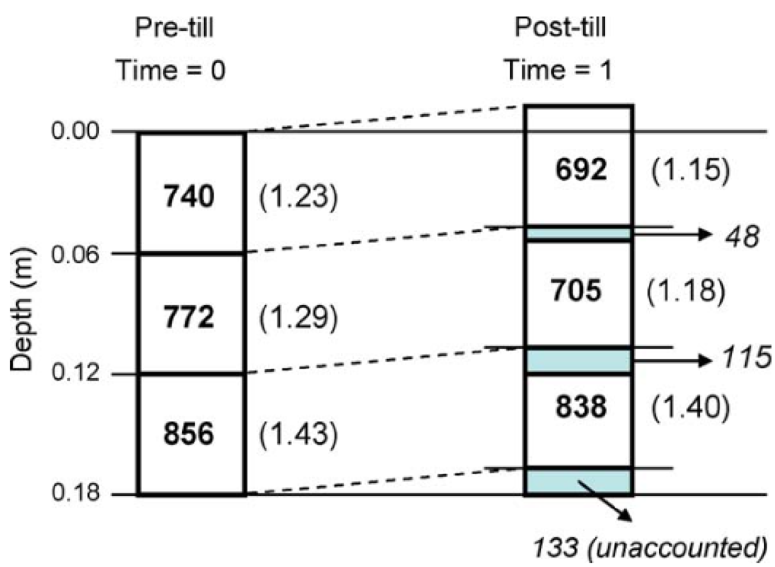


**Figure 7: Tillage decreases bulk density, expanding the volume that the soil layer takes up. Because of this expansion, some carbon is now below the depth of measurement. Figure from Lee et al (2009).**

**Edge-of-Field and Whole-Farm Interventions:**

A PES program compensating for carbon sequestration on agricultural land might also incorporate payments for vegetation stored in woody biomass. Eligible land-uses might include silvopasture, riparian buffers, farm woodlands and other agroforestry.

## FLOOD MITIGATION

Since the devastating flooding during Tropical Storm Irene in 2011, Vermonters have been working to make our communities safer and more resilient to flooding. Climate change is expected to increase the frequency of severe storms in Vermont, making this work even more important. Soils and vegetation high in watersheds can play an important role in buffering peak stream-flows during storm events, protecting people, homes, and infrastructure in the valleys below. Flood-control services provided by coastal wetlands, riparian wetlands and upland forests are well-studied, but comparatively little research has been done on the impact of agricultural soil health on flood risk[4] .

Our estimates attempt to be inclusive of all damages done by flooding, but estimates of damages, especially indirect damages, are highly imprecise.

### Valuing Flood Risk:

To value reductions in flood risk from soil health practices and indicators, we must ask several questions:

- First, *what is the total, annual value of Vermont's flood risk?*
- Second, *what proportion of this risk can be attributed to agriculture?*
- Third, *how much of a difference does reducing runoff by a given amount reduce that risk?*

A summary of the steps that we took can be seen in Table 2.

Rare, extreme flooding events account for the majority of flooding damages to buildings and property (Figure 8). Tropical Storm Irene accounts for 70% of all National Flood Insurance Program payouts for non-winter flooding in VT since 1976[5] (Federal Emergency Management Agency., 2021a). Given that Irene caused severe damages outside of mapped flood zones and through landslides not covered by the NFIP, this proportion is likely an underestimate of its contribution to historical flood damages. Similarly, 71% of all flood-related payments from the USDA Crop Insurance Program since 1988 were made for damages caused by Irene (Risk Management Agency, 2021). 89% of all FEMA-assessed damage to VT homes since 2002 was associated with Irene (Federal Emergency Management Agency., 2021b). Between 65% and 91% of FEMA grants associated with flooding made to Vermont communities since 1998 were associated with Tropical Storm Irene (Federal Emergency Management Agency., 2021c) [6]. Additionally, most smaller flood events have been due to storms that featured extreme rains (>3 inches) on a more localized basis (VT Emergency Management, 2018).

[4] For a review of what research has been done, see Alaoui et al (2018).
[5] We would expect soil-health to have very little impact on winter flood damages from ice-dams and snowmelt, though other agricultural management practices might have an impact.
[6] This very wide range is due to the "Severe Storm" categorization – a significant proportion of damages from "severe storms" can be due to wind and ice, but much is due to flooding.

This aligns with national data showing that 98% of flood damages come from 25% of flooding events (Wobus et al., 2014). From this, we focus our analysis on "generational storms" of the scale of TS Irene, and secondarily on "major storms" that occur more frequently but on a more limited geographic scale.

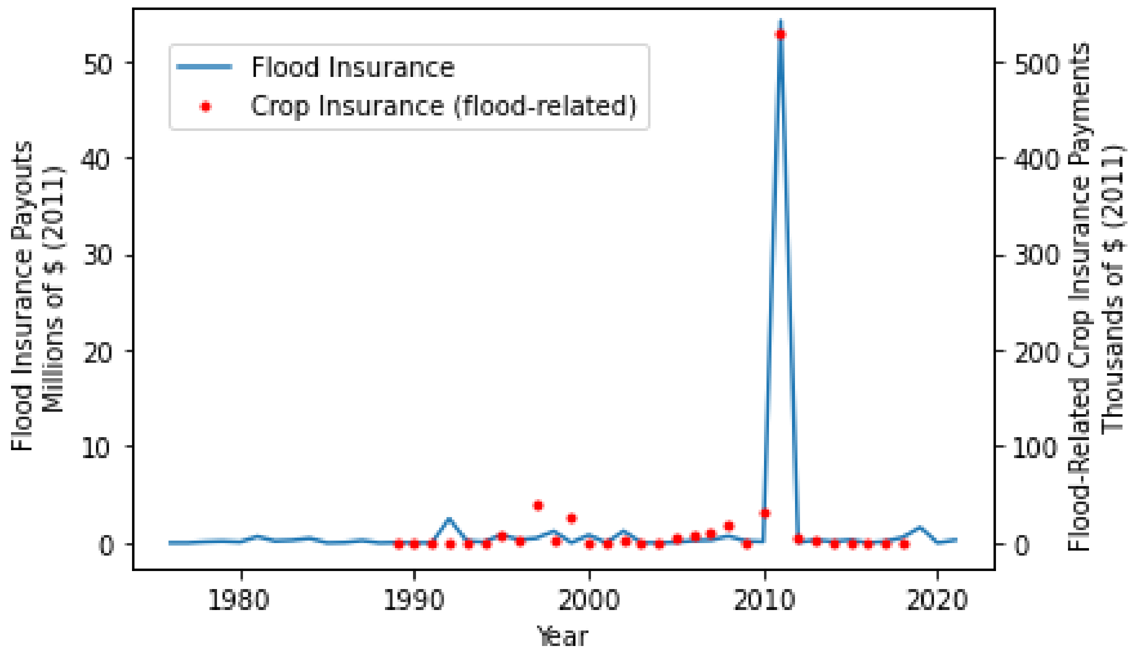


**Figure 8: Annual Payouts in Vermont for Federal Flood Insurance, and Crop Insurance Payouts for Flood-Related Damages. (Note that Crop Insurance payments are plotted at exactly 1/100$^{th}$ scale compared to Flood Insurance).**

Hurricane Irene resulted in an estimated $733 million in total damages[7], $860 million in 2020 dollars. This estimate appears to include nearly $400 million in damage to transportation infrastructure, >$10 million in damages to agriculture and $130 million to rebuild the state government complex Waterbury (VT Emergency Management, 2018). Damages to private real estate likely exceeded $150 million, and include nearly $28 million in damages assessed by FEMA and nearly $43 million in claims to the national flood insurance program (Federal Emergency Management Agency., 2021a), though these are likely only a fraction of total damages to private property[8]. We account for non-financial losses from flooding (loss of life, disruption of work and school, etc) by rounding this number up to $1 billion, though a higher number might be reasonable. Vermont sustained one other storm of this scale in the last 100 years, in 1927, and two other, somewhat smaller major flood disasters, in 1938 and 1973.

[7] The Irene Recovery Report (Rose & Ash, 2013) estimates $850 million in total assistance paid out.
[8] The NFIP claims database holds 1009 claims made on Irene in VT, while the Irene Recovery Report estimates 3500 homes and businesses damaged/destroyed and the State Hazard Mitigation Plan estimates ~5000. Assuming that 24% of damages were covered by the NFIP we get ~$180 million in damages to real estate.

**Table 2: Summary of Steps Used to Value Mitigating 1 acre-inch of runoff from Large Storms.**

| **"Generational Storms"** | **Number** | **Derivation** |
|---|---|---|
| Damages: | $1 billion | TS Irene was about $1 billion in USD 2020 |
| Frequency: | 50-year | TS Irene is a roughly a 100-year return time. We account for other large storms (e.g. 1973, 1938) by halving this. |
| Value of Risk | $20 million / year. | $1 billion / 50 |
| Agriculture's Contribution | 5% | Agricultural Land contributed 4.6% of damage-weighted runoff and was 5.6% of the landcover upstream from damaged communities (weighted by federal assistance). |
| Value of Agriculture's contribution | $1 million /year | $20 million * .05 |
| Climate Change Adjustment (next 30 years) | $1.5 million/ year | Increase by 50% |
| Value of runoff abatement | $.90/acre-inch/year | $1.5 million / 1.7 million acre-inches of runoff from agriculture during Irene. |
| **More Frequent Storms** | | |
| Flood Insurance as a proportion of total damages. | 4.8% | TS Irene has the best accounting for a wide range of costs. Flood insurance claims account for 4.8% of accounted for damages incurred during Irene. For smaller storms, this proportion ought to be greater; the larger the storm, the greater the proportion of damages outside of designated Flood Hazard Zones. Using this number is likely to cause us to **over-estimate** flood damages. |
| Flood Insurance Claims | $900,000/ year | Excluding Irene, average non-winter NFIP claims are $900,000/year from 2000-2020[9]. |
| Value of Annual Damages | $18.8 million/year | $900,000 / .048 |
| Agriculture's Contribution | 9% | Agriculture is 9.5% of the landcover above communities damaged by non-Irene floods (weighted by payments to towns by FEMA). It makes up a smaller proportion of runoff, though the exact proportion is not clear. |
| Value of Agriculture's Contribution | $1.7 million /year | $18.8 million / .09 |
| Climate Change Adjustment (next 30 years) | $2.6 million / year | Increase by 50% |
| Value of Runoff Abatement | $2.60 / acre-inch / year | Assume average agricultural runoff from more-frequent storms is 1 ¼ inch per acre, allocated among 800 thousand acres of crops, hay and pasture. |
| **Total Value of Runoff Abatement** | $3.60 / acre-inch / year | $.90 + $2.60 = $3.50. |

[9] This number is sensitive to the chosen starting year for recent annual damages. For 2011-2020 the average is $1.55 million /year, for 2012-2020, the average is $290,000/year. For other ranges, the number is intermediate.

**What is Agriculture's Contribution to Flood Risk?**

Based on the National Land-Cover Dataset, 14% of Vermont land is in agriculture: cropland, hay, pasture and orchards. This land is larger located in places with lower value for flood run-off mitigation, because they have lower elevation and lower slope. This lower-elevation land has lower flood mitigation value due to:

1- Lower rainfall at lower elevations.

2- Fewer people and structures downstream. A large proportion of farmland is very close to Lake Champlain or the Connecticut River. Figure 9 shows that the highest concentration of farmland is in areas that flow directly into Lake Champlain, and within each sub-watershed, the largest concentration of agricultural land tends to be below heavily populated areas.

3- Gentler slopes below mean little ability for run-off to gain erosive power or quickly inundate downstream areas.

An estimate using the Curve Number Method[10] yields about 10% of total run-off from agricultural lands during Hurricane Irene (Figure 10). This runoff largely occurred in areas below the most-impacted communities. Weighted by total Federal Assistance money from Irene (Vermont Public Radio, 2013), the average Irene-damaged community in Vermont had 5.6% agricultural landcover in its upstream watershed, and 4.6% agricultural runoff. Based on a 50-year return time, $1 billion damages and a 5% contribution of agriculture to damages, the annual value of agricultural runoff from a generational storm is roughly $1 million/year. Adjusting 50% upwards for climate-change risks and allocating among 1.7 million acre-inches of agricultural runoff during Irene yields $.90/acre-inch/year in large-storm runoff.

The risks from smaller storms are smaller, even on annualized basis, but agriculture plays a larger role. Using Irene as a template, National Flood Insurance claims account for about 4.8% of total flood damages. Non-winter, non-Irene flood insurance claims average $900,000/year over the last 20 years, suggesting $18.8 million in flood damages per year. Among smaller storms that still received federal disaster declarations, the average flood-damaged municipality (again, weighted by disaster assistance) in Vermont had 9.5% agricultural landcover upstream. Adjusting slightly down to 9% account for lower runoff from agricultural land yields $1.7 million/year in agriculture-related flood damages. Adjusting 50% upwards for climate change, and assuming an average of 1.25 inches average agricultural runoff yields $2.60/acre-inch in flood mitigation services.

Combining the values for generational and medium-to-large flood events, our final median estimate is $3.50.

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[10]The NRCS curve number method is an empirical model which uses land management, soil hydrologic group and slope to predict the rainfall-runoff relationship for a location. The CN Method is still state-of-the-art for runoff estimation, it is one of two options used for estimating runoff in the Soil and Water Assessment Tool (SWAT) and the Agricultural Policy Environmental Extender (APEX). For more information, see: https://acwi.gov/hydrology/minutes/nrcs_cn_method.pdf

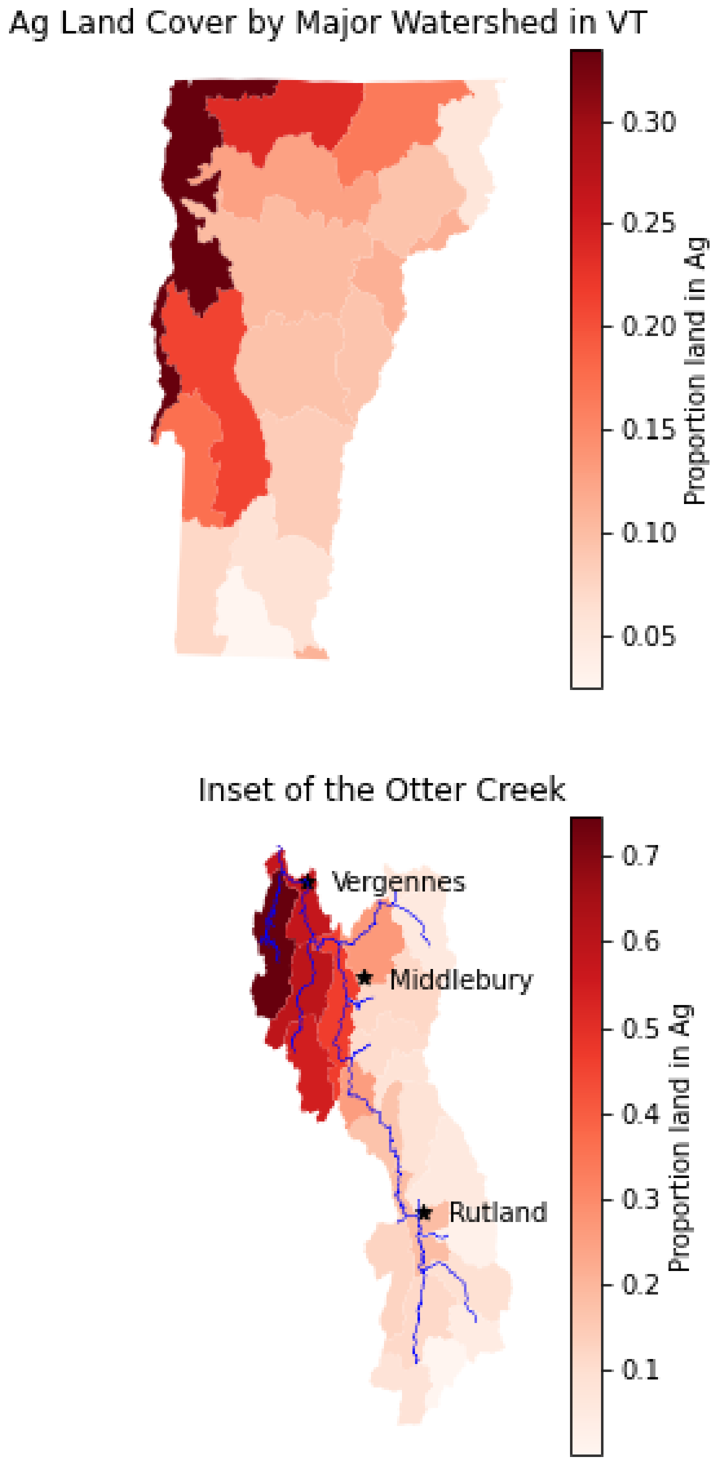


**Figure 9: Percentage of Land in Agricultural Land Cover in Vermont Sub-watersheds. Data from 2014 NCLD.**

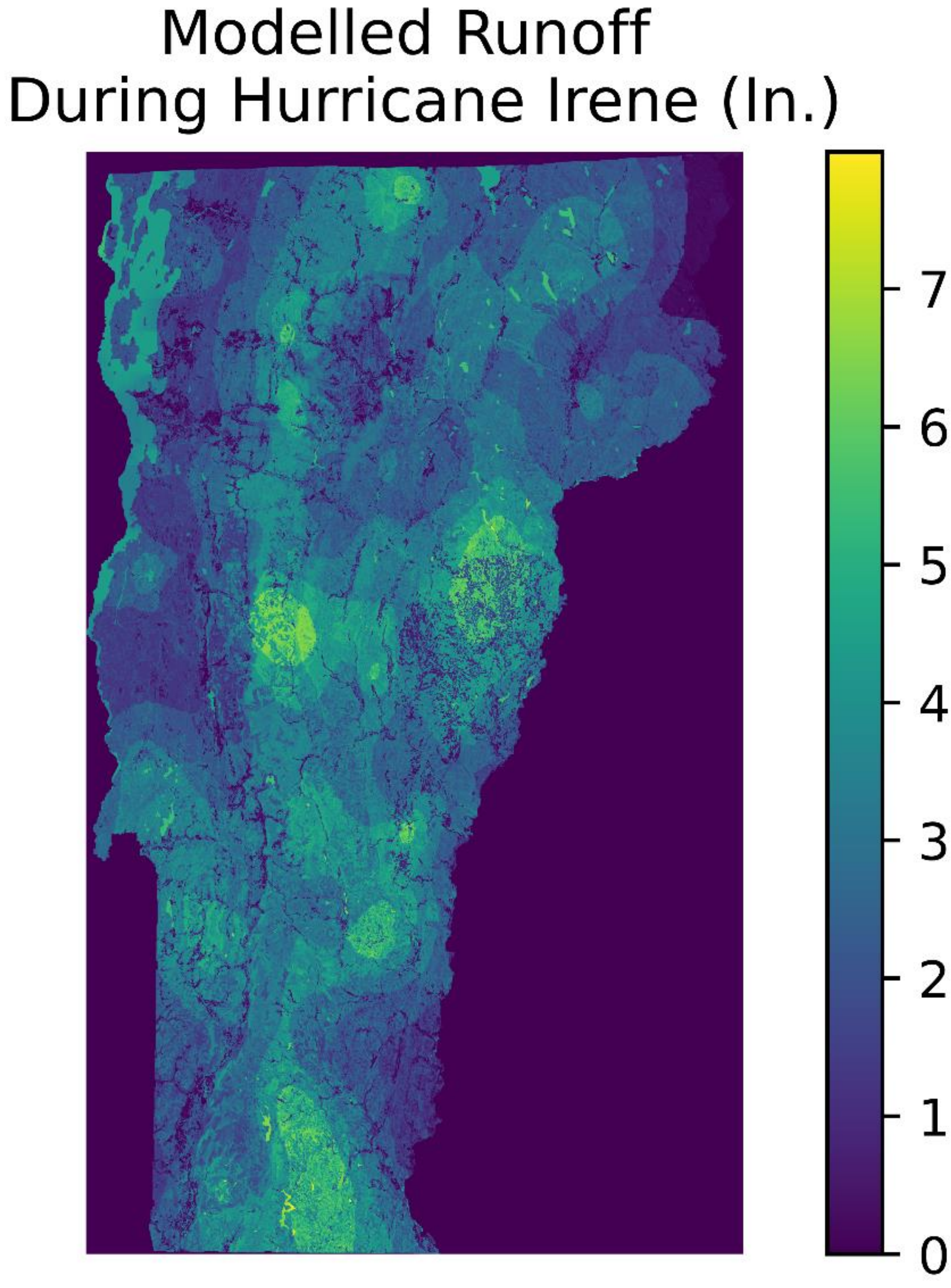


**Figure 10: Runoff During Hurricane Irene, Modelled Using the NRCS Curve Number Method**

**Biophysical Methods:**

For reductions in runoff from practice changes, we use the Curve Number Method to estimate runoff volume. For very large storm events, this method is known to under-estimate runoff volumes, and thus likely exaggerates the impacts of practices.

For reductions in runoff from soil health, we estimate reductions using two methods, and then present the average value. First, we simply estimate the increase in excess available water-holding capacity until saturation for the soil. We estimate this value using several pedo-transfer functions and assume that the soil's plant-available water capacity is about 60% utilized at the beginning of the storm. Second, we use similar pedo-transfer functions to parameterize soils for the Green-Ampt Equation[11] and then simulate an 8-hour, 4-inch storm. The reported results are an average of these two methods.

**Results:**

Current evidence supports only moderate impacts on major-storm runoff from changes in soil health or changes in soil-health practices. The below figures (Figures 11 & 12) summarize simulation results for a major storm, with 4-inches of rainfall in 8 hours, approximating the average rainfall volume on agricultural land during hurricane Irene and other major storms. Except for conversion of row crops to Hay, impacts are generally between 1/6 inch and ½ inch. Monetary valuations are unlikely to reach levels relevant to farmers, at least on average. Corresponding monetary valuations are under $3.00/acre/year, except for permanent hay (Figure 11).

For the best soil-health scenario, runoff reductions range from ¼ to ½ an inch, and are estimated as about 2x as large using the simple water-deficit method as compared to process-based simulations; corresponding payments are all at or below $2/acre/year.

[11] The Green-Ampt equation is a simulation model describing how rainfall infiltrates into a soil, based on several soil physical parameters, including available water capacity and saturated hydraulic conductivity. For a detailed explanation, see: http://www.alanasmith.com/theory-Calculating-Effective-Rainfall-The-Green-Ampt-Method.htm. The Green-Ampt method is over 100 years old, but still widely used; along with the curve number method, it is one of two options for simulating runoff in SWAT and EPIC/APEX. We implement a Green-Ampt model with 3 distinct soil layers.

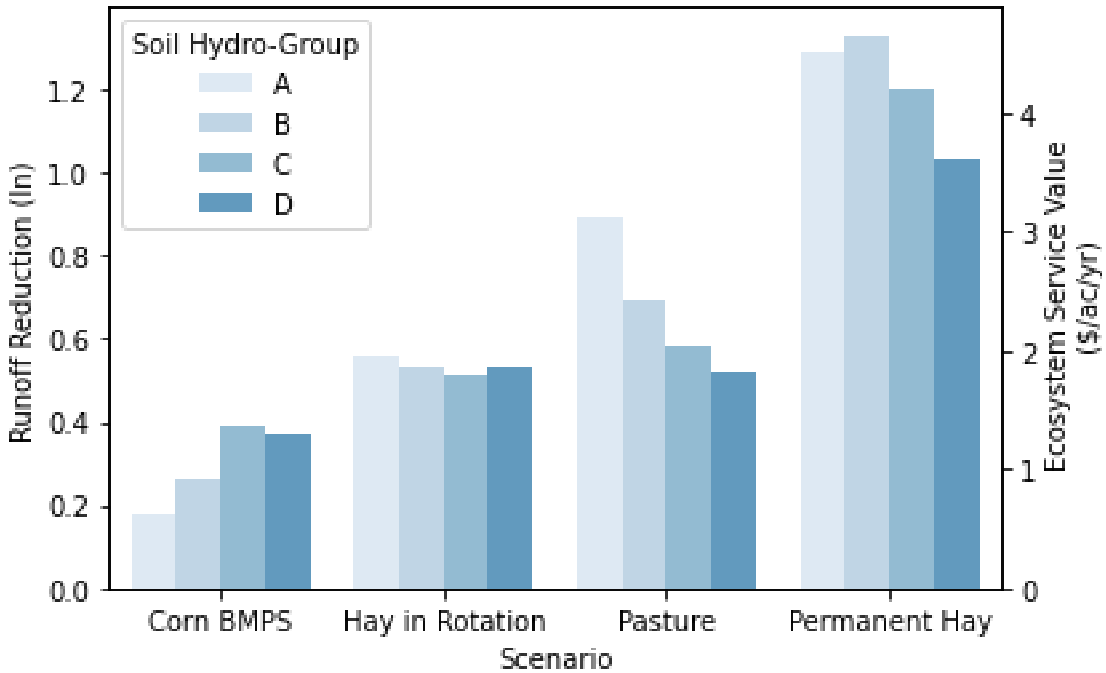


**Figure 11: Runoff Reductions (4-inch storm) and hypothetical Average Payments for Flood-Control Services for Changes in Soil Health by Practice (Reference Case: Row Crops, Conventional Tillage)**

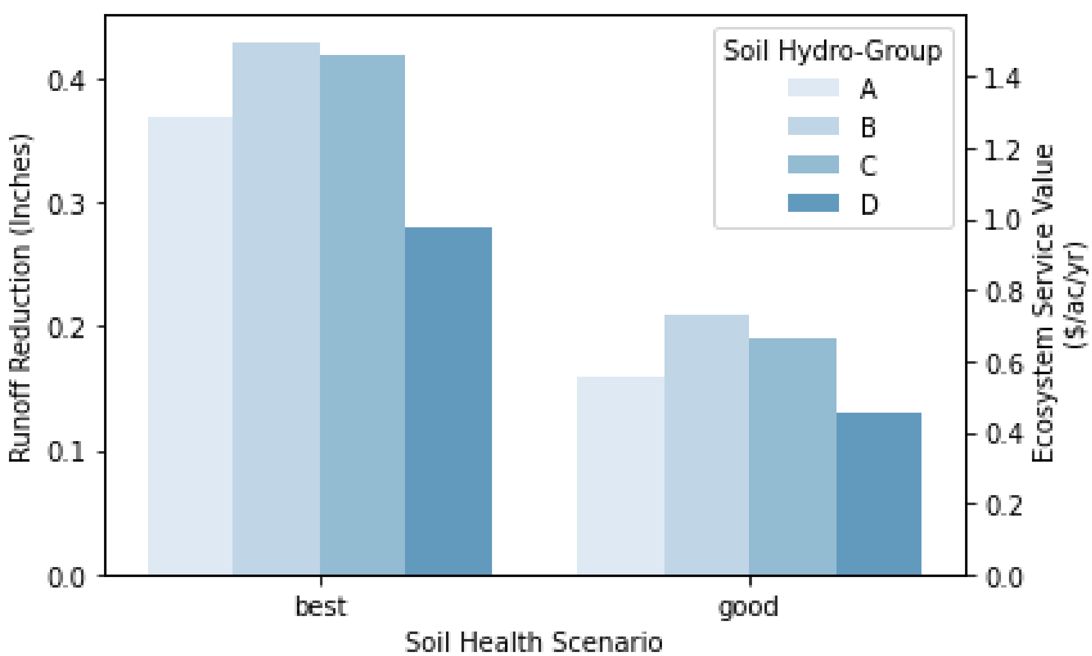


**Figure 12: Runoff Reductions (4-inch storm) in Good and Best Soil-Health Improvement Scenarios.**

**Variation in Service provisioning and Value:**

There is little variation between soils in their capacity to improve stormflow-retention service provision, but large spatial variation in the value of stormflow mitigation. As noted before, a large proportion of Vermont farmland is at very low elevations, and many of the most at-risk communities are relatively high up in the watershed. To examine variability of potential flood-control services, we use the method described by Watson and colleagues (2019)[12] to quantify spatial variability in the "demand" for flood-control services. The analysis below keeps the *average* value of flood mitigation services on agricultural land but weights the ES value by this flood control demand score.

Our results show that many farm fields contribute little to flood-control services, simply because they have few flood-prone structures downstream of them. On the other hand, a few farm fields in the "right" locations can contribute to protecting many at risk structures. If payments were apportioned based on flood risk, these fields could be eligible for substantial payments for their reduction in potential runoff during large storms. These farm fields are largely located in the upper reaches of the Winooski River watershed, one of the few places in the state where a high concentration of farms is upstream from substantial infrastructure and settlement (Figure 13). Table 4 presents the range of Ecosystem Service values per acre-inch obtained by allocating the $4.1 million in total potential flood-control value to each agricultural area by its flood-control demand score, as does Figure 13.

| ES Value (per year /per acre-inch) | % of Agricultural Area in Category |
|---|---|
| < $0.25 | 23.4% |
| < $1 | 27.6% |
| $1 - $2 | 10.8% |
| $2 - $5 | 14.6% |
| $5 - $10 | 6.3% |
| >$10 | 7.2% |

**Table 3: Distribution of economic values for reducing runoff in a 4-inch rain-event by 1 inch.**

[12] The flood control demand-score method assigns 1 "point" for each structure designated as "at risk" to flooding and allocates that point equally among all areas upstream of the structure. Each landcover pixel gets a score as a sum of all the points it receives for structures downstream.

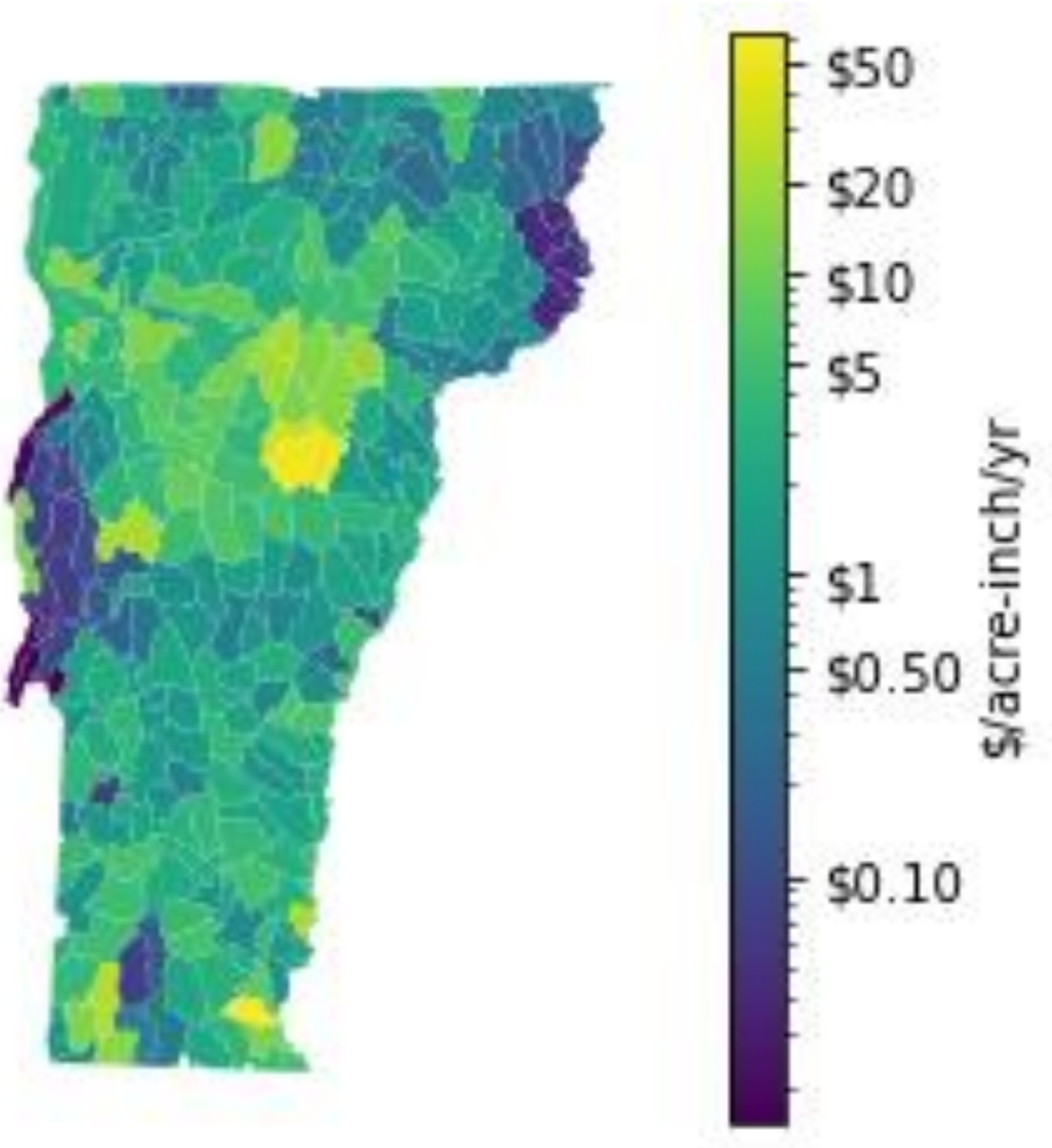


**Figure 13: Annual Value of Reducing Large-Storm Runoff from Agricultural Land by 1 acre-inch, by Sub-watershed, Averaged by Sub-Watershed.**

**Caveats and Additional Areas for Examination:**

There are several weaknesses in our analysis, some of which may bias our estimates towards underestimating actual benefits, others which may bias them in the other direction. These are summarized in Table 4. Most important is the assumption of linear damages- some runoff generating events do no damage at all, while many floods are subject to threshold effects, where a small increase in flow may cause dramatically greater damages. Several types of damages may not be well-accounted for, including damages to natural capital and the economic and social costs of disruption while damaged infrastructure is un-usable.

A few factors may cause our estimates to be too high. First, some flood events occur when the soil is already saturated. This gives little opportunity for increased water-infiltration capacity to mitigate runoff. Some of our methodological simplifications may also tilt the estimate upwards. First, our estimates of agricultural land-use in damaged towns' contributing watersheds are sometimes much higher than they should be to reflect the areas contributing the most to flood risk. Second, we limit our runoff reduction analysis to 4-inch rain events; runoff reductions will be somewhat smaller in inches for smaller rain events, though larger in percentage terms.

**Edge-of-Field and Whole-Farm Interventions:**

Several agriculture-related interventions that are not within the scope of this report may be very important. Agricultural land-use may influence stream channel flooding dynamics. This may be very important, especially when rivers can access their floodplains, or forested riparian buffers slow the movement of floodwaters. While not estimated in our report, non-soil-health practices such as riparian buffers, constructed wetlands, artificial ponds and swales could increase water retained in the landscape as well, and a PES program might pay for these services. Additionally, where agricultural lands are threatened by development pressures, agricultural land-cover provides substantial flood-control ecosystem services relative to developed land with substantial impervious surfaces.

**Table 4: Major Sources of Uncertainty in Our Estimates of Flood Control Ecosystem Services**

| **Factors That May Lead to Under-estimates** | **Explanations/Examples** |
|---|---|
| Assumption of Linear Damages | Reducing floodwaters by 90% in many cases could eliminate 100% of damages. Given the small role of agriculture in the most disastrous floods, this is minor for "Generational Floods," but may be a larger issue for more minor flooding. |
| Social Costs of Infrastructure Disruptions | The costs of re-building a roadway are easy to quantify. The costs of that roadway being less usable while being rebuilt are not. Similar for power outages, etc. Hurricane Irene was noted to cause disruptions to the crucial foliage tourism season. |
| Repair Costs of very minor floods. | Damages from very frequent but small floods cause damages to public infrastructure (e.g. dirt roads) that may be difficult to quantify. |
| Damages to Natural Capital | Flooding and fluvial erosion contribute substantially to many hard-to monetize damages from pollution. These include damages from erosion and nutrient deposition, as well as hazardous waste contamination. |
| **Factors that May Lead to Over-estimates** | |
| Many of the most damaging storms occur when soils are saturated. | Greater infiltration capacity gives little runoff-mitigation benefit when the soil is already saturated. Our estimates for increases in infiltration are based on soil available water capacity being 60% filled. |
| Town watersheds incorporate all areas upstream, sometimes overestimating the importance of agricultural landcover. | Often, small waterways (with very low agricultural landcover) cause a large proportion of damages. For instance, the Cold River (<2% ag landcover), accounted for a large proportion of Irene damages to Clarendon and Rutland. The total upstream agricultural landcover for both of these towns, which is what is used in the analysis, is >7.5%[13]. |
| Simulating Runoff only for Large Storms | For smaller storms, the % of runoff averted by soil health is greater, but the absolute quantity will be smaller. For soil-health practices, the curve-number method is known to underestimate runoff in severe storms, leading to higher estimates of mitigation values. |

[13] Similarly, most damage in the town of Hartford (~8.9% agriculture in its watershed) occurred in the Village of Quechee on the Ottauquechee River, which has less than half the upstream agricultural landcover (~3.7%). In a non-Irene example, severe flooding in Bellows Falls (Rockingham VT, 6.5% Agriculture in its watershed) in 2021 was due to the Hyde Hill Brook, which appears to have no agriculture in its watershed.

## EROSION

While soil erosion is often thought of a direct threat to agricultural sustainability and productivity[14], it is also associated with many off-site environmental harms. One of the largest of these harms is the contribution of nutrients in eroded soil to eutrophication, which is covered in the Phosphorus and Nitrogen sections of this report. These costs include stream and reservoir sedimentation, which can reduce recreational value, harm wildlife and fish, increase flood risks and reduce the working life of dams.

### Valuing Impacts of Soil Erosion:

For soil-erosion impacts, we use a simple "value-transfer" method- we use the calculations of other researchers of damage costs. Pimentel and colleagues (1995) estimated the total non-eutrophication external costs from water-driven soil erosion for the US, and these average to $3.50/ton. Adjusting for inflation yields $6/ton in 2020 USD. These harms and their costs are very sensitive to waterways that the sediments eventually flow into. As such, the numbers below are merely illustrative, but they do show that erosion mitigation may constitute a substantial proportion of the public benefits of soil-health and soil health practices.

### Biophysical Methods:

The Universal Soil Loss Equation (USLE) is a family of simple models used to estimate soil erosion losses from farm fields. One of the parameters of USLE relates directly to soil properties, the soil erodibility or "K" factor. Wischmeier and colleagues developed an equation linking soil texture, organic matter and saturated hydraulic conductivity to the K factor (Wischmeier et al., 1971)[15]. We use this equation to estimate the impacts of soil health changes on soil erosion, using a family of reference scenarios for the other USLE parameters. Likewise, for soil-health practices, we alter the "C" or crop-cover factor of USLE to develop estimates of changes in erosion losses with practice changes.

### Results:

Figure 14 summarizes the reduction in soil erosion from changing practices from the reference case of conventional corn. The "hay" scenario covers all perennial forages, including rotational hay, permanent hay and permanent pasture. Figure 15 summarizes reductions in erosion from improved soil health.

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[14] For on-farm values of erosion control, we can consider the cost of replacing organic matter lost in eroded soil. There are roughly 400 lbs of organic matter in a cubic yard of compost. If the eroded topsoil contains about 4% organic matter, then replacing organic matter requires roughly 1 ton of compost for each 5 tons of topsoil lost.

[15] The Wischmeier equation is the default option for calculating the K factor in SWAT. Another popular option is the equation developed for EPIC/APEX by Williams (1995). The Wischmeier equation is chosen because it incorporates two soil-health parameters (Organic Matter and Saturated Hydraulic Conductivity), while the Williams equation incorporates only Organic Matter. The Wischmeier method also covers greater range of soil organic matter concentrations than the Williams method.

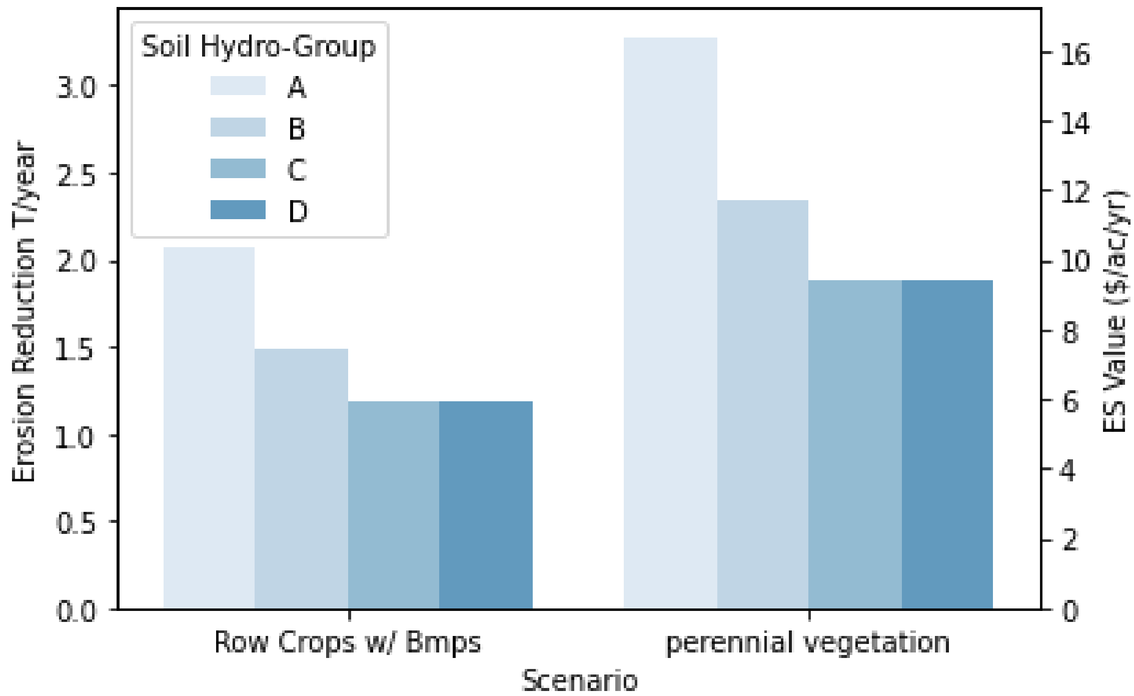


**Figure 14: Reductions in Erosion for Soil Health Practices and Corresponding Ecosystem Service Value**

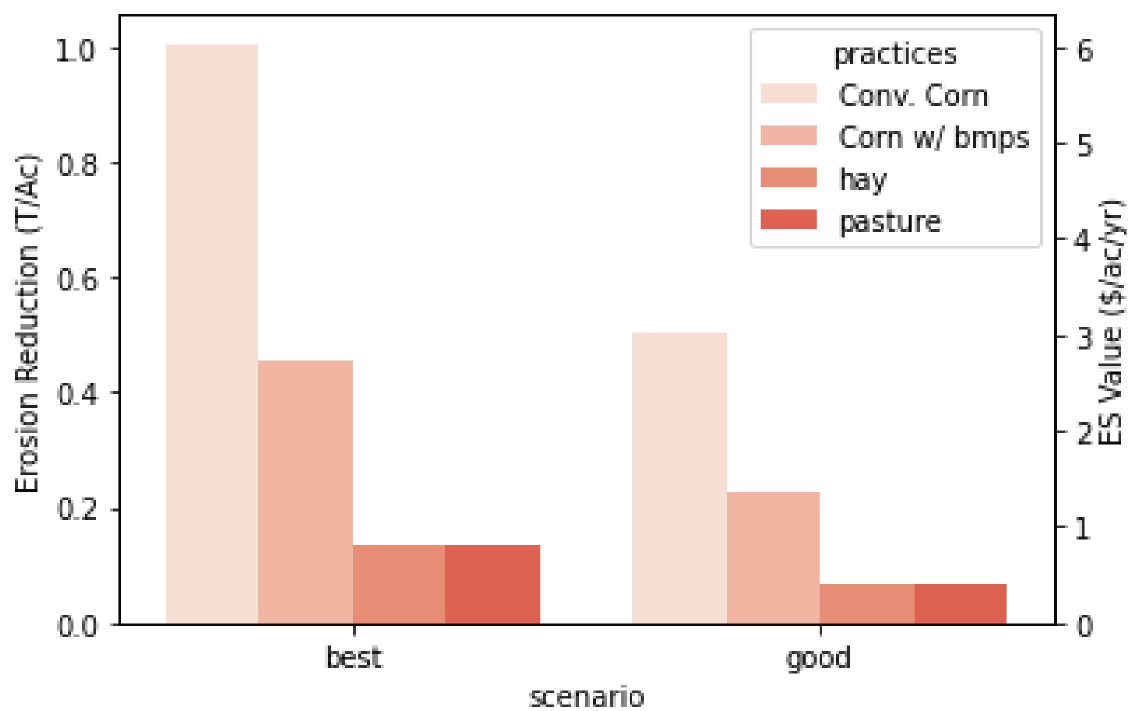


**Figure 15: Reduction in Erosion for Soil-Health Indicator Scenarios and Ecosystem Service Value**

**Sources of Variation:**

The value of erosion reduction services from healthy soil is higher on fields with steeper slopes, and higher on fields growing annual crops than those with perennial vegetation. We expect the same magnitude of soil-health improvements to have the same percentage impact on soil erosion, making the economic value much larger on fields that have high potential for erosion losses. The spatial variability in the value of damages done by a ton of eroded sediment is likely very important, but not explored in this study.

**Edge-of-Field and Whole-Farm Interventions:**

Riparian buffer zones and other practices which can intercept eroded sediment before it enters waterways can greatly reduce the downstream damages of erosion. Likewise, substantial quantities of sediment can be generated streambank erosion, which can be mitigated by numerous conservation practices. A PES program might consider paying for these services as well.

## NUTRIENT RETENTION: PHOSPHORUS

Phosphorus enrichment is the largest source of freshwater eutrophication globally, and agriculture is the largest contributor. This is also true in Vermont for both the Lake Champlain and Lake Memphramagog watersheds. In Lake Champlain, numerous cyanobacteria blooms have degraded water quality, causing major economic, quality-of-life, and health impacts on the people living near the lake. Healthy soils and some soil-health related practices may be helpful for retaining phosphorus on farm fields and keeping it out of freshwater bodies.

### Valuing P Reductions:

Estimating the marginal harms from an additional lb. of Phosphorus emitted into Lake Champlain is beyond our capabilities for this short report[16]. Instead, we utilize a replacement cost/substitute cost method. We use estimated costs of required Wastewater Treatment Facility (WWTF) upgrades and calculate their marginal cost of P reduction. This approach assumes that the State of Vermont has demonstrated its willingness to pay for P abatement through investments in hard infrastructure.

We estimate the abatement curves for Phosphorus from WWTFs using data from the Lake Champlain TMDL (Tetra Tech, 2014) and the Vermont ANR (2015). Two abatement curves are used: one which uses the current wastewater load (in millions of gallons / day), and the other that uses the permitted load. To make each curve, we calculate each plant's abatement cost ($/lb P) by dividing the annualized cost for each plant required to make upgrades by the annual required reduction in P load. Plants are then sorted by cost, lowest to highest. Figure 16 represents the cost of removing the last pound of phosphorus to achieve a given reduction fraction, assuming that the cheapest reduction opportunities are utilized first.

By taking the average of these two curves at the 85$^{th}$ percentile, we calculate an abatement cost of $100/lb. We use the 85$^{th}$ percentile because the TMDL and other P-reduction plans focus on agriculture for the largest reductions in part because these are believed to be more cost-effective. This number is also equivalent to payments being made by current state programs. Approximately 75% of Vermont's agricultural land is in the Memphremagog or Champlain Basins, we assume Phosphorus loss outside of these areas to be worth 20% the value in these impaired watersheds, yielding an average value of $80/lb.

[16] Consulting with other researchers, we were advised that generating a useful social cost of Phosphorus for the various lake segments would take more time than we had for this entire report. A recent paper by Gund Institute researchers (Gourevitch et al., 2021) estimated that meeting the TMDL in the Missisquoi watershed would yield nearly $1 million/year in water quality benefits from 87.96 metric-tons/year of reduced P loading. This yields a social cost of Phosphorus on the order of only $5/lb in this watershed.

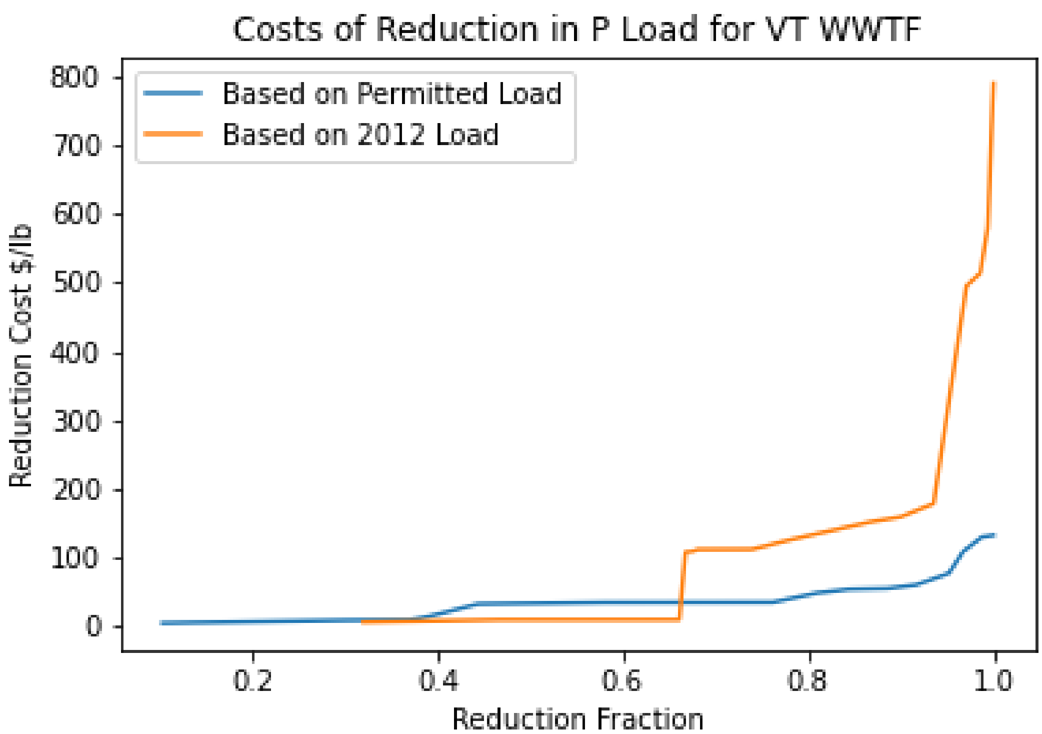


**Figure 16: Abatement Curves for Reducing Phosphorus Loads for Vermont Wastewater Treatment Plants.**

**Methods for Estimating Reductions:**

To estimate reductions in P losses, we use the VT P Index (Jokela, 1999), a spreadsheet-based model used by farmers for nutrient management planning. The VT P Index includes the soil-health practice scenarios we investigate here, so these are directly simulated. The results presented average over a family of reference scenarios for innate site characteristics (slope, distance to water, soil type).

We were able to incorporate changes in soil health indicators in two ways. First, the P Index requires an erosion rate, for this we utilize the impacts on erosion losses developed previously. Second, we simulate the impacts on runoff across a wide variety of storms using the same methods as described in the section on flooding, to estimate how soil health reduces growing-season runoff, and therefore P losses in that runoff. The results presented average over reference scenarios for management parameters.

**Results:**

Figure 17 shows the estimated reductions in P losses for practice changes, relative to conventional corn. Figure 18 shows our results for the soil improvement scenarios.

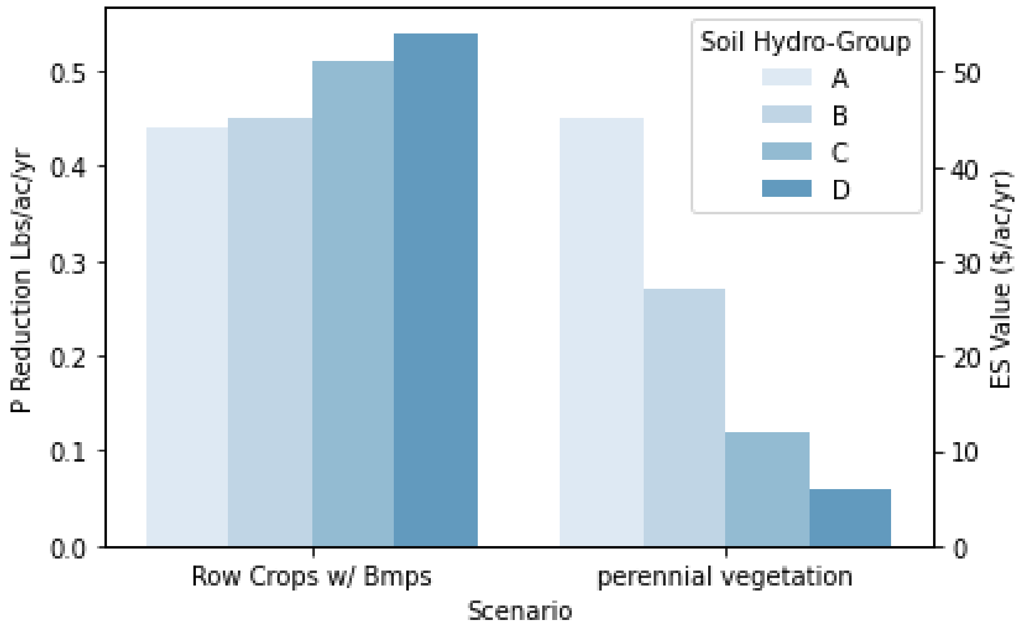


**Figure 17: Reductions in P Losses for Soil Health Practices Scenarios and Ecosystem Service Value. Row crops with Conventional Practices as Baseline.**

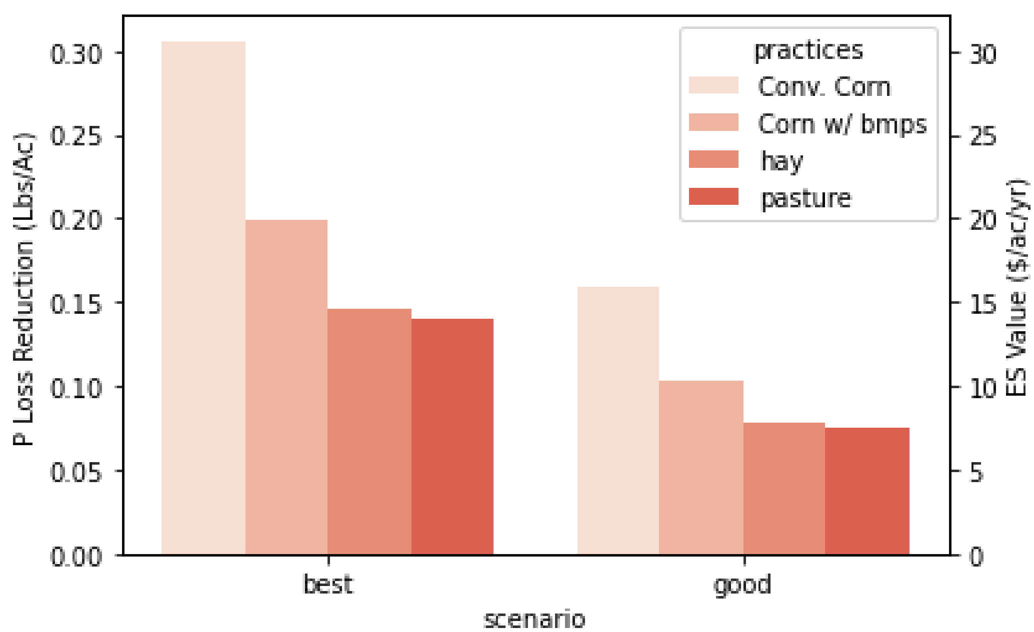


**Figure 18: Reductions in P Losses for Soil Health Indicators Scenarios and Ecosystem Service Value.**

**Sources of Variation in Service Value:**

Improved soil health can reduce erosion and can reduce runoff, which are two important pathways for Phosphorus losses from farm fields. All else equal, we should expect reductions erosion and runoff to be proportional to P losses from erosion and runoff. As noted above, these reductions in P loss may be largely or fully offset by increased subsurface losses of P, on fields with substantial connections to waterways via subsurface drainage. Similar to erosion-control, the quantity of P-retention services provided by healthy soils is proportional to the field's potential to lose Phosphorus. Healthy soils provide a greater benefit in P reduction on fields growing annual crops, on steeper slopes, closer to waterways. Therefore, a large increase in soil health has a smaller value if other P-conserving practices are already implemented.

Beyond this analysis, most important soil-health indicator for P loss is **soil test phosphorus**. High soil-test phosphorus levels make it extremely difficult to keep P losses from farm fields to acceptable levels.

The largest source of variation in the value of P retention services is location in a sub-watershed. P retention is much more valuable in the basins of Lakes Champlain and Memphramagog than it is in watersheds connected to the Connecticut and Hudson Rivers, with a few exceptions[17]. It may be even more valuable in specific sub-watersheds flowing into highly impaired lakes and ponds.

**Caveats and Areas for Future Work:**

Soil health metrics, and soil health practices can be effectively linked to expected reductions in erosion and runoff, nutrient losses through these pathways are proportional to these quantities, holding all else equal. Greater water infiltration may, however, increase nutrient losses downward through the soil profile, which may be especially harmful in soils with pattern tile drainage, or other direct connections to waterways via subsurface flow.

These results should be interpreted with caution. The estimates for *soil-health practices* are directly drawn from the Vermont P-Index, and therefore reflect the feedback that farmers are already getting about how to reduce their contributions to P loading.

**Edge-of-Field and Whole-Farm Interventions:**

As with other services, edge-of-field practices can contribute greatly to reducing P loads, and could be incorporated into a broader PES program.

[17]Other than Lake Champlain, there are 8 waterbodies that are either declared impaired by P and/or have had a TMDL drawn up for P since 2001. Two of these waterbodies: Ticklenacked Pond in Ryegate, and the Black River, are outside of the Champlain or Memphremagog Basins.

## OTHER ECOSYSTEM SERVICES

### Nitrogen:

There are several types of N losses from agriculture which harm ecosystems and human health through a variety of pathways. Gaseous losses, including ammonia, nitric oxides and nitrogen dioxide contribute to acidification of water and soil, and can damage air quality both directly and through their impacts on particulate formation. Water-borne losses of nitrate, including leaching and runoff, can damage drinking water resources and contribute to eutrophication of marine ecosystems. Nitrogen lost from the soil can also change form after leaving the soil - nitrate in runoff will eventually be denitrified and turn into $N_2O$, NO or $NO_2$, while some gaseous emissions will be deposited in soils that they may subsequently leach from.

### Valuing N Losses:

The spatial complexity of N emissions and their harms calls for a full study of its own, but table 5 summarizes best-estimates of the average economic harms done by different pathways of reactive nitrogen emissions in the United States. Note that some of these, such as respiratory disease, may have much smaller impacts in VT, which has low population density and few population centers downwind.

**Table 5: Average US Values for Damage costs from Different types of Nitrogen Emissions, based on work of Sobota et al (2015)**

| N Loss Pathway | Damage Valuation per Lb of N | Largest component | Note |
|---|---|---|---|
| $NO_x$ | $15.88 | Respiratory Disease (79%) | Beneficial for climate |
| $NH_3$ | $6.07 | Ecosystem Change (69%) | Beneficial for climate |
| $N_2O$ | $11.11 | Climate Change (87%) | Climate number from (Marten & Newbold, 2012) |
| Surface freshwater | $10.33 | Eutrophication (85%) | |
| Groundwater | $1.33 | Colon Cancer (72%) | |
| Costal Water | $12.12 | Fisheries (71%) | |

### Impacts of Soil Health on N Losses:

In general, improving soil organic matter increases N mineralization, which may somewhat increase soil N losses. This impact may be reduced if farmers account for the increased N mineralization from organic matter in their nutrient planning and apply less N to their fields in manure and fertilizer. Decreases in bulk density can significantly decrease $N_2O$ losses and runoff losses (Nawaz et al., 2013) but may increase losses through leaching.

Table 6 Provides example data for N losses from dairy-based cropping systems in VT, and the economic valuation of a 25% decline of N losses through each pathway. The social benefits of reducing N losses to this degree are substantial, larger than most other ecosystem service benefits.

Some soil health practices may actually increase N losses. For example, in a recent dairy cropping systems experiment (Barbieri, 2021), the Corn BMP scenario, which uses the best-management practices we use for our BMP scenario[18], increased gaseous N losses when compared to more standard agronomic practices. Detailed modelling on how soil-health changes may impact soil nitrogen status is technically feasible but would take more time than we had for producing this report.

**Table 6: Average N losses from different Pathways in a Dairy Cropping Systems study in Vermont, and the Ecosystem Services Value of a 25% Decrease.**

| | Hay | | Corn | |
|---|---|---|---|---|
| | Lbs/Ac/Year | Value 25% decrease | Lbs/Ac/Year | Value 25% decrease |
| Leaching | 4 | $1 | 6 | $2 |
| Runoff | 8 | $18 | Negligible | $0 |
| N2O | 2 | $14 | 8 | $19 |
| NH3 | 6 | $3 | 6 | $8 |
| Total | | $36 | | $29 |

**Valuation of Soil Biodiversity:**

Several options exist for valuing soil biodiversity, though none of these are feasible within the scope of this study. There are 3 general types of values contributed by soil biodiversity. First, soil biodiversity is linked to supporting ecosystem services including nutrient cycling, predation, and soil aggregation, which may enhance other ecosystem services, including crop production and the services discussed in this paper. Second, soil biodiversity may have insurance value: soil biodiversity may enhance the resilience and stability of important soil ecosystem services. Lastly, soil biodiversity may have existence value, the people in Vermont may derive economic value from knowing that their soils are biodiverse, regardless of any direct impacts on human-wellbeing.

The first two types of value are important questions, but too little research exists to conduct a meaningful valuation of changes in soil biodiversity; no available models can link a unit-change in soil biodiversity with a unit-change in soil resilience. For existence value, stated-preference methods, such as contingent valuation surveys could be used to understand Vermonter's willingness-to-pay to improve soil biodiversity, but these methods would likely be unreliable for something so abstract.

[18] Recall that the Corn BMPs are focused on reducing Phosphorus losses. A different set of BMPs could reduce N losses.

**Conclusion and Next Steps:**

In this report, we estimate the levels and values of 4 ecosystem services promoted by healthy soils and by soil-health practices. We show that the public values of these services are of reasonable size and may justify a program for payments for Ecosystem Services. While these estimates are necessarily rough, they also can provide general guidance to understanding the sources of variability in these values and their relative magnitudes.

Several areas require further work to better understand. First, better estimates of Nitrogen may be quite valuable - the relative magnitudes of benefits from reducing N losses look to be substantial. Second, estimates of the benefits from edge-of-field practices and other non-soil-health practices may also be useful. For example, it is likely that re-establishing riparian forest would have similar or greater per-acre benefits for all four of these ecosystem services than any soil-health practice or improvement[19]. Third, further research could refine the estimates of the dollar values of other Ecosystem Services. For all of the services included the estimates that we provide for their dollar values are preliminary and would benefit from refinement.

The science on the ecosystem services from healthy soil is still in its infancy. The science linking sustainable and regenerative agriculture practices to soil health increases and ecosystems services is also new and sparse. While new research will continue to refine our understanding, the estimates provided here can guide the creation of policy with the information we have today.

[19] For instance two recent studies (Gourevitch et al., 2020, 2022) find very large impacts from floodplain forest restoration on flood risks downstream, aboveground forest carbon storage in the Northeast exceeds 30/T acre (Heath et al., 2002) and buffer zones along agricultural fields are highly effective at reducing sediment and nutrient loading (Yuan et al., 2009).

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